study be conducted within 6-12 months to examine how planned cockpit sleep opportunities have been incorporated into airline procedures. That study would examine how the procedures were implemented and their effectiveness. This might take the form of a survey or include some field data collection. The results of that follow-up study might then lend support for further refinement of procedures and future implementation in other flight environments.

2.0 INTRODUCTION

2.1 Background

The rapid multiple time-zone changes, sleep disturbances, circadian disruptions, and long, irregular work schedules associated with long-haul flight operations can result in pilot fatigue. Safety and operational effectiveness during long-haul flights may be compromised because of reduced pilot performance and alertness. Pilot fatigue in long-haul flight operations is a major safety concern.

Several sources lend support to this concern. Long-haul wide-body flight operations have almost a three-times higher loss ratio than combined short- and medium-range flights (ref. 1). Also, cockpit crew error, where pilot fatigue may be a contributory factor, has been related to 75% of aircraft losses since 1959 (ref. 1). NASA's Aviation Safety Reporting System (ASRS) receives reports every month from long-haul crews describing the role of fatigue, sleep loss, and sleepiness in significant operational errors. Reported errors have included altitude deviations, improper fuel calculations, track deviations, landings without clearance, and landings on incorrect runways. These reports are not surprising, for many pilots describe anecdotally the overwhelming fatigue and sleepiness associated with all-night flying over the ocean. The flight deck environment, with constant background noise, dim lighting, and various levels of automation, can contribute to the difficulty of remaining vigilant and awake under these circumstances. As trips progress and as the number of flight legs increases, so too can the cumulative effects of sleep loss and fatigue.

Extensive research has shown that there are at least three interrelated biological sources of the fatigue, sleep loss, and sleepiness experienced in long-haul flight operations (e.g., refs. 2-4): (1) circadian disruption, (2) cumulative sleep loss, and (3) sleepiness rhythm. Each of these factors will be reviewed briefly to provide greater understanding and background for the causes of fatigue and sleepiness in long-haul flying.

Human circadian (i.e., about 24 hr.) rhythms are internally controlled by a biological clock in the brain. There are many examples of biological functions that fluctuate over a 24 hr. period, such as sleep and wakefulness, body temperature, and activity. Transmeridian flights rapidly transport this internal human circadian clock to new external time zones. The internal biological clock, however, is unable to adapt quickly and instead adjusts to the new external time zone at a slow rate. The result is a desynchrony between biological rhythms and external synchronizers (e.g., light, meals) and a disorganization of internal physiological and psychological rhythms as the circadian clock slowly adjusts to the new environmental time. Most pilots are familiar with these factors as primary causes of their experience of fatigue and other symptoms of jet lag. It has been shown that the severity of circadian adjustment effects is related to the number of time zones crossed. The more time zones crossed, the greater the adjustment required by the circadian clock. It is also known that there are wide individual differences in ability to adjust to new time zones. Some individuals can experience severe effects following a time-zone change of only 1 or 2 hr.

One basic biological property of the human circadian clock accounts for the generally familiar experience of easier and faster adjustment when flying west than when flying east. If allowed to run at its natural rhythm, the average internal biological clock would actually have a cycle slightly longer than our 24 hr. day, about 25 hr. This means that there is a natural, inherent tendency to lengthen our day. Therefore, when traveling a westward, the circadian day is lengthened (or delayed) and promotes adjustment to the new time zone. Conversely, when flying eastward the circadian day is shortened (or advanced), contrary to the natural tendencies of the internal clock. Therefore, generally, adjustment will be slower and more difficult.

A second primary consequence of circadian disruptions by rapid time-zone changes is that the sleep/wakefulness rhythm is out of phase, or desynchronized, with the new environmental time. For example, pilots may attempt to sleep at the new environmental night time, when their internal circadian clock says it is high noon and they should be wide awake. The result is usually sleep loss caused by a short-duration sleep, often precipitated by a premature spontaneous awakening. Over time, this shortened sleep duration results in a cumulative sleep loss and sleep debt. For example, if an individual gets 1 hr. less sleep per night than is usually needed, by the end of 1 week he or she will have accumulated the equivalent hourly loss of a full night's sleep. The severity of the sleep disturbance will affect the total cumulative sleep debt. However, the loss of even 1 hr. of sleep will contribute to increased waking sleepiness, with the potential effect being even greater when combined with prior cumulative sleep loss (ref. 5). The potential results of sleep loss are performance lapses, slowed mental processing and decision-making, reduced memory function, and more negative mood (ref. 6).

Scientific research has shown that separate from nocturnal sleep, the biological clock also regulates the daily level of sleepiness and alertness, that is, sleepiness rhythm. In a 24 hr. period, there are two distinct periods of maximal sleepiness for a normal, healthy, nonsleep-deprived person: during the early morning hours (about 4-5 A.M.) and during the mid-to-late afternoon hours (about 3-5 P.M.) (ref. 7). Typically, individuals would attempt to be asleep during the 4-5 A.M. period of sleepiness, when there are minimal environmental distractions and a decreased body temperature. Also, most people have experienced the increased sleepiness that occurs during the mid-to-late afternoon, which is when most naps are taken (ref. 8). During the afternoon most individuals are active, and in an environment with stimulation, and the body temperature is high, allowing them to continue their activities without being overcome by sleepiness. These internally controlled periods of maximal sleep tendency greatly enhance the likelihood that sleepiness, and perhaps sleep, will intrude into wakefulness. Although a variety of strategies are used to combat this period of biological sleepiness, it is clearly a window of increased vulnerability to reduced performance and alertness. It is also known that sleep loss exacerbates this situation by increasing the level of sleepiness at all times of the day. This information is important in identifying periods of maximal physiological sleepiness that occur every 12 hr. If a night flight over the ocean coincides with a window of maximal sleepiness, then there is an increased vulnerability to involuntary sleepiness.

These three factors interact and provide the physiological basis for the fatigue, sleep loss, and decreases in alertness, performance, mood, and mental function associated with long-haul flight operations. One compensatory response to this fatigue, sleep loss, and sleepiness is the occurrence of involuntary sleeping in the cockpit, with increased frequency of occurrence during night flying (refs. 9, 10). Evidence, beyond the purely anecdotal, suggests that this is occurring in long-haul flight operations. One operational study reported observational data from three-person commercial airline crews flying international routes (ref. 10). The flight deck observers on these flights noted any episode when crewmembers apparently napped while in their cockpit seat. In conjunction with the daily log and observer notes, the results indicated that crewmembers napped, depending on the specific trip schedule, on from 5% - 20% of the flights available for cockpit napping. Generally, these naps were reportedly unplanned, though at times a crewmember would inform the others of a need for a brief rest period.

It was suggested that these percentages are most likely underestimates of the actual incidence of napping, planned or otherwise, in long-haul flight operations. Recently, Gander et al. reported data based on crew's subjective logs that indicated the timing and duration of their naps (ref. 3). The log data indicated that on average, 11% of crewmembers reported taking naps on the flight deck when an opportunity was available during a flight. These naps ranged from 10-130 min. in length and averaged 46 min. It is unclear from these data which naps were planned and which involved uncontrolled, involuntary napping.

Current civil aviation regulations do not sanction sleep in the cockpit, though it is unclear how often this strategy is actively used to overcome sleepiness and fatigue during long-haul transmeridian flights (ref. 11). The U.S. Air Force and some foreign carriers currently use cockpit rest periods to combat fatigue. The potential for devastating consequences as a result of increased sleepiness and fatigue and the associated decrease in vigilance and performance are compelling reasons to address these complex issues through operationally relevant empirical research.

2.2 Cockpit Rest Periods: Relevant Laboratory Research

Based on scientific and operational considerations, Graeber, et al. have suggested that planned and controlled napping on the flight deck may be one way of overcoming the sleepiness and decreased performance that can be associated with nonaugmented long-haul flying (ref. 12). Empirical research data in both laboratory and field experiments support this notion. A brief, planned nap can minimize the adverse behavioral, physiological, and psychological effects of sleep loss and circadian desynchronization (refs. 13-16). Generally, most healthy young adults can nap on demand, even in a lighted room with sounds, if sitting in a comfortable chair (refs. 17, 18).

Naps can have a beneficial effect on self-reported alertness in nonsleep-deprived individuals and on sustained performance in sleep-deprived individuals (for a review see refs. 8, 19). Research indicates that taking a nap before a significant sleep-debt accumulation is more important to its effectiveness than the circadian position (refs. 13, 14). Thus "prophylactic napping" can prevent some of the effects of sleepiness (ref. 13). The scientific literature, therefore, supports the proposition that planned and controlled napping on the flight deck may be an effective countermeasure to the fatigue and sleepiness experienced in long-haul flight operations.

The length of the planned cockpit rest periods is considered to be a critical factor. Laboratory research has suggested that a brief nap, less than 1 hr. long, would be sufficient to improve subsequent alertness and performance (ref. 8). A longer nap increases the possibility that deep sleep will occur and, therefore, might increase the potential effects of sleep inertia (i.e., the sleepiness that can be experienced when one is awakened from deep sleep). For a more complete discussion of these issues and the relevant laboratory research, see reference 20.

2.3 Purpose

The primary goal of this research was to examine the effects of a planned cockpit rest period on pilot performance and alertness in long-haul nonaugmented flight operations. It was hypothesized that a short, planned opportunity to sleep during a low-workload portion of flight (i.e., cruise) would act as a "safety valve" for fatigue and sleepiness. Performance and alertness following the nap should be improved, especially during critical phases of operation, such as descent and landing.

2.4 Scientific and Operational Issues

This research was designed to examine a variety of basic issues. The following are some of the specific questions that were addressed:

1. Given the opportunity, will pilots be able to sleep in their cockpit seats? What will be the quantity and quality of the sleep obtained in the cockpit environment?
2. Will a nap improve subsequent performance, such as sustained attention or vigilance, or prevent it from worsening? Will performance be maintained or improved during critical phases of operation, such as descent and landing?
3. Will a nap improve subsequent alertness, as indicated by physiological measures of alertness/sleepiness, or prevent it from worsening? Will alertness be maintained or improved during critical phases of operation, such as descent and landing?
4. If a planned nap improves performance and alertness, how long do the positive effects last?
5. Could planned rest opportunities, and sleep, compromise flight safety?

6. What operational guidelines should be considered for implementation of planned cockpit rest in long-haul operations?
7. Would planned cockpit rest be an improvement over the current situation of uncontrolled spontaneous napping in nonaugmented long-haul flying?

3.0 METHODS

3.1 Study Design Overview

This study involved regularly scheduled transpacific flights with nonaugmented B-747 three-person crews. Volunteer pilots were randomly assigned to one of two study groups. The rest group (RG) was allowed a 40 min. opportunity to sleep during the overwater cruise portion of flight. On a rotating basis, individual crewmembers were allowed to nap in their cockpit seat. The no-rest group (NRG) was not offered a nap opportunity, and instead performed their usual operational activities throughout the flight.

Before the study began, briefings regarding the operational and scientific goals of the project were held with the Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), airline management, and pilot union officials. The FAA co-sponsored the project and provided crucial support through its sanction for cockpit rest. It was vital that all concerned parties be informed and support the project. The two airlines approached agreed to participate in the study. Each airline's participation was dependent on the availability of specific transpacific trip schedules and volunteer pilots.

3.2 Subjects

All subjects were line pilots who volunteered to participate in the study. The data in this report were based on pilots flying the regularly scheduled transpacific trip outlined in the next subsection. After this specific schedule had been selected, the trip was marked in subsequent bid packages to indicate that pilots bidding this trip would be contacted by NASA researchers for volunteer participation in a fatigue study. Once pilots were assigned to the trip, a NASA principal investigator contacted them regarding the project. Initial contact was by letter and telephone with a description of the ongoing NASA program to study crew fatigue and jet lag and an outline of the proposed study. The specific requirements of participation were described in detail and questions or concerns were addressed thoroughly. It was clearly indicated that involvement would be completely confidential, that the FAA and their airline had sanctioned the cockpit rest, and that their participation was completely voluntary at all times, including once they had begun the protocol. Therefore, volunteers were informed that they could withdraw at any point in the study. No financial or other remuneration was offered or provided for participation. If pilots volunteered, then information packets (written and video materials), questionnaires (e.g., logbooks), and some equipment (e.g., actigraphs) were given to them.

It has been the general policy of this NASA Fatigue Countermeasures Program to provide complete confidentiality and anonymity for all pilots participating in studies. This effect required additional sanctions and guarantees by the FAA and participating airlines for pilots in the rest group to be allowed a cockpit rest period. Participating volunteers were assigned an identification code that was used for all data collected. Only identification numbers were associated with any identifiable component of the project.

3.3 Trip Characteristics

The specific trip pattern studied was chosen to meet certain scientific and operational conditions. These conditions included multiple transpacific crossings, some equal groupings of day and night flights, comparable flight lengths, regularly scheduled, nonaugmented crews, low